PATENT
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DISSIPATIVE CERAMIC BONDING TIP

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BACKGROUND OF THE INVENTION

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A ~~1.~~ Field of the Invention

This invention relates to bonding tool tips and more particularly to dissipative ceramic bonding tips for bonding electrical connections.

A ~~2.~~ Description of the Prior Art

Integrated circuits are typically attached to a lead frame, and individual leads are connected to individual bond pads on the integrated circuit with wire. The wire is fed through a tubular bonding tool tip having a bonding pad at the output end. These tips are called capillary tips. An electrical discharge at the bonding tool tip supplied by a separate EFO (electronic flame off) device melts a bit of the wire, forming a bonding

ball. Other bonding tools do not have the center tube, but have a feed hole or other feature for feeding the wire along, as needed. Some bonding tips have no such wire arrangement, as the wire is supplied, as in magnetic disk recording devices, where the wire is insulated and bonded to a magnetic head and then to a flexible wire circuit.

When the bonding tip is on the integrated circuit die side of the wire connection, the wire will have a ball formed on the end of the wire, as above, before reaching the next die bonding pad. The ball then makes intimate contact with the film formed on the die pad on the integrated circuit. The bonding tip is then moved from the integrated circuit die pad, with gold wire being fed out as the tool is moved, onto the bond pad on the lead frame, and then scrubbed laterally by an ultrasonic transducer. Pressure from the bonding tool tip and the transducer, and capillary action, 'flows' the wire onto the bonding pad where molecular bonds produce a reliable electrical and mechanical connection.

Bonding tool tips must be sufficiently hard to prevent deformation under pressure, and mechanically durable so that many bonds can be made before replacement. Prior art bonding tool tips were made of aluminum oxide, which is an insulator, but provides the wearability to form thousands of bonding connections. Bonding tool tips must also be electrically

designed to produce a reliable electrical contact, yet prevent electrostatic discharge damage to the part being bonded. Certain prior art devices have a one or more volt emission when the tip makes bonding contact. This could present a problem, as a one volt static discharge could generate a 20 milliamp current to flow, which, in certain instances, could cause the integrated circuit to fail due to this unwanted current.

U.S. Patent No. 5,816,472 to Linn describes a durable alumina bonding tool "without electrically conductive metallic binders." U.S. Patent No. 5,616,257 to Harada describes covering the bonding tool electrode with an insulating cap or covering "made of a ceramic material" to produce a large electrostatic discharge that creates bonding balls of stable diameter. U.S. Patent No. 5,280,979 to Poli describes a vacuum wafer-handling tool having a ceramic coating "made with a controlled conductivity" to prevent a large electrostatic discharge.

SUMMARY OF THE INVENTION

Electrically, dissipative ceramic bonding tips for bonding electrical connections to bonding pads on electrical devices are disclosed. In accordance with the principles of the present invention, to avoid damaging delicate electronic devices by any electrostatic discharge, a bonding tool tip must conduct electricity at a rate sufficient to prevent charge buildup, but not at so high a rate as to overload the device being bonded. In other words, it is desirable for the bonding tip to discharge slowly. The tip needs to discharge to avoid a sudden surge of current that could damage the part being bonded. For best results, a resistance in the tip assembly itself should range from 10^5 to 10^{12} ohms. The tools must also have specific mechanical properties to function satisfactorily. The high stiffness and high abrasion resistance requirements have limited the possible material to ceramics (electrical non-conductors) or metals, such as tungsten carbide (electrical conductor).

In the present invention, bonding tool tips with the desired electrical conduction can be made with three different configurations.

First, the tools can be made from a uniform extrinsic semiconducting material which has dopant atoms in the appropriate concentration and valence states to produce sufficient mobile charge carrier densities (unbound electrons or holes) which will result in electrical conduction in the desired range. For example, polycrystalline silicon carbide uniformly doped with boron.

Second, the tools can be made by forming a thin layer of a highly doped semiconductor on an insulating core. In this case the core provides the mechanical stiffness and the semiconductor surface layer provides abrasion resistance and provides a charge carrier path from the tip to mount which will permit dissipation of electrostatic charge at an acceptable rate. For example, a diamond tip wedge that is ion implanted with boron.

Third, the tools can be made by forming a lightly doped semiconductor layer on a conducting core. The conducting core provides the mechanical stiffness and the semiconductor layer provides abrasion resistance and provides a charge carrier path from the tip to conducting core, which is electrically connected to the mount. The doping level is chosen to produce conductivity through the layer which will permit dissipation of electrostatic charge at an acceptable rate. For example, cobalt bonded tungsten carbide coated with titanium nitride carbide.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view vastly enlarged of a capillary bonding tool tip;

Figure 2 is a cross-sectional view, vastly enlarged, of a capillary-type construction of the operating end or tip of a bonding tool;

Figure 3 is a cross-sectional view of a bottle-neck capillary bonding tool tip;

Figure 4 is an isometric view of a wedge bonding tool tip;

Figures 5a and 5b are top and front views, respectively, of the wedge design bonding tool tip as shown in conjunction with Figure 4; and

Figure 6 is an isometric view of a typical commercial apparatus utilized in the wire bonding of a semiconductor integrated circuit chip or other apparatus.

Figure 7 a cross section of embodiments of Fig. 2 having two layers.

Figure 8 a cross section of embodiments of Fig. 3 having two layers.

Figure 9 a cross section of embodiments of Fig. 5 having two layers.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 illustrates a typical capillary bonding tool 10. Such bonding tools are usually about one-half inch (12 - 13 mm) long and about one-sixteenth inch (1.6 mm) in diameter. The bonding tool tip 12 itself is usually from 3 to 10 mils (0.08 to 0.25 mm) long. Running the length of the tool itself, but not viewable in Figure 1, is a tube hole which would accommodate a continuous fed length of gold wire (not shown).

Figure 2 is a highly enlarged, cross-sectional view of the capillary bonding tool 10 as shown and described in Figure 1. Only that portion of the bonding tool 10 shown within the dotted circle in Figure 1 is shown in Figure 2. Tool tip 12 has the hole tube 14 which may run the entire length of bonding tool 10. The exit hole 18 is where the wire (not shown) would exit the tool tip 12. If a ball is formed on the wire, the ball would be seen immediately adjacent the exit hole 18. The chamfer 16 at the exit hole 18 is there for at least two reasons. First, to accommodate a ball that has been formed at the end of the gold wire. Also, the chamfer surface 16 is provided to allow for smoother looping of the wire as the bonding tool 10 is moved from the bonding pad on an integrated circuit to the bonding pad (not shown) on a lead frame of an integrated circuit assembly.

The wedge tool for disk drive bonding is used to capture the insulated wire, lay it on the head and ultrasonically bond it there.

Figure 3 is an alternative embodiment of a bonding tool 10 showing similar features, as the hole tube 14, chamfer surface 16, and exit hole 18. This bonding tool tip, named a bottle-neck capillary tip, is provided for narrower bond situations where the bonding pitch (distance between the centers of the bonding pads) is smaller and smaller as the dimensions of an integrated circuit get smaller, or the number of circuits on a chip get larger, but the die area remains more or less constant.

Figure 4 shows still another type of bonding tool 10. This bonding tool is typically used with an integrated circuit die mounted on a lead frame (not shown). This is the case where the wires from the integrated circuit are not connected from the die to connections directly in an integrated circuit package, but from the integrated circuit die to a lead frame, which technology is well known to skilled practitioners in the art. The composition of the lead frame being different than the composition of an integrated circuit package, the tip 12 of the bonding tool 10 must be different to accommodate the different physical attributes of the integrated circuit lead frame, as seen in Figures 5a and 5b.

Figure 6a illustrates a typical wire bonding machine 60 for use in bonding wire leads in magnetic disk drive units. Shown within the dotted circle is the bonding tool 10. The bonding tool 10 is mounted to arm 66 which is moved in the desired directions by the apparatus of wire bonding machine 60. Such a machine is available as Model 7400 from the West Bond Company in Anaheim, California.

Typical bonding tips available on the market today are made of an insulator of alumina (Al_2O_3), sometimes termed aluminum oxide. This is a very hard compound which has been used on commercial machines with success as it provides a reasonably long life in use as a wire bonding tool. To insure that it is an insulator no conductive binders are used in these bonding tips. However, as stated previously, the problem has existed that an electrostatic discharge from the bonding tool making contact with the bonding pad of the desired circuit can damage the very circuit it is wiring up.

However, in accordance with the principles of the present invention, to avoid damaging delicate electronic devices by this electrostatic discharge, a bonding tool tip must conduct electricity at a rate sufficient to prevent charge buildup, but not at so high a rate as to overload the device being bonded. It has been determined that the tool must have electrical conduction greater than one ten-billionth of a mho (i.e. > 1 x

10 raised to the minus 12th power reciprocal ohms) but its electrical conductivity must be less than one one-hundred thousandth of a mho (i.e. < 1 X 10 raised to the minus fifth power reciprocal ohms). The resistance should be low enough so that the material is not an insulator, not allowing for any dissipation of charge and high enough so that it is not a conductor, allowing a current flow. For best results, a resistance in the tip assembly itself should range from 10^5 – 10^{12} ohms. For example, for today's magnetic recording heads 5 milliamps of current will damage them. Preferably, for today's magnetic recording heads, no more than 2 to 3 milliamps of current should be allowed to pass through the tip to the head.

The tools must also have specific mechanical properties to function satisfactorily. The high stiffness and high abrasion resistance requirements have limited the possible material to ceramics (electrical non-conductors) or metal, such as tungsten carbide (electrical conductor). The tip should have a Rockwell hardness of about 25 or above, preferably of about 32 or above. The tip needs to be able to last for at least two bondings.

In the present invention, bonding tool tips with the desired electrical conduction can be made with three different configurations.

First, the tools can be made from a uniform extrinsic semiconducting material which has dopant atoms in the

appropriate concentration and valence states to produce sufficient mobile charge carrier densities (unbound electrons or holes) which will result in electrical conduction in the desired range. For example, polycrystalline silicon carbide uniformly doped with boron.

Second, the tools can be made by forming a thin layer of a highly doped semiconductor on an insulating core. In this case the core provides the mechanical stiffness and the semiconductor surface layer provides abrasion resistance and provides a charge carrier path from the tip to the mount, which will permit dissipation of electrostatic charge at an acceptable rate. For example, a diamond tip wedge that has a surface that is ion implanted with boron or a doped ceramic.

Third, the tools can be made by forming a lightly doped semiconductor layer on a conducting core. The conducting core provides the mechanical stiffness and the semiconductor layer provides abrasion resistance and provides a charge carrier path from the tip to conducting core, which is electrically connected to the mount. The doping level is chosen to produce conductivity through the layer which will permit dissipation of electrostatic charge at an acceptable rate. For example, cobalt bonded tungsten carbide coated with titanium nitride carbide.

Figures 7, 8 and 9 illustrate the two-layered structure of the last two configurations. This structure is not intended to

be specific to the type of tool tip. Rather, it could be used for any bonding tool tip. In the second and third configurations, the outer layers are labeled 71, 81 and 91 and the cores are labeled 72, 82 and 92. In the second configuration, mentioned above, layers 71, 81 and 91 are highly doped semiconductor and the cores 72, 82 and 92 are insulators. In the third configuration, mentioned above, layers 71, 81 and 91 are lightly doped semiconductor and the cores 72, 82 and 92 are conductors. No significance should be attached to the relative thickness or scale of the portions of the layer 71. Layer 71 may or may not have a uniform thickness.

Dissipative tools can be manufactured by any of the following methods.

1. Mixing, molding and sintering reactive powders. Fine particles of the desired composition are mixed with organic and inorganic solvents, dispersants, binders, and sintering aids are then molded into oversize wedges. The pieces are carefully dried, and heated slowly to remove the binders and dispersants and then heated to a high enough temperature so that the individual particles sinter together into a solid structure with low porosity. The heat-treating atmosphere is chosen to facilitate the removal of the binder at a low temperature and to control the valence of the dopant atoms at the higher temperature and while cooling. After cooling, the pieces may be

machined to achieve the required tolerances. The pieces may then be treated to produce the desired surface layer by ion implementation, vapor deposition, chemical vapor deposition, physical deposition, electro-plating deposition, neutron bombardment, or combinations of the above. The pieces may be subsequently heat treated in a controlled atmosphere to produce the desired layer properties through diffusion, recrystalization, dopant activation, or valence changes of metallic ions.

2. Hot pressing reactive powders. Fine particles of the desired composition are mixed with binders and sintering aids and then pressed in a mold at a high enough temperature to cause consolidation and binding of the individual particles into a solid structure with low porosity. The hot pressing atmosphere is chosen to control the valence of the dopant atoms. After cooling and removal from the hot press, the pieces may be machined to achieve the required tolerances. The pieces may then be treated to produce the desired surface layer by ion implantation, vapor deposition, chemical vapor deposition, physical deposition, electo-plating deposition, neutron bombardment or combinations of the above. The pieces may subsequently be heat treated in a controlled atmosphere to produce the desired layer properties through diffusion,

recrystalization, dopant activation, or valence changes of metallic ions.

3. Fusion casting. Metals of the desired composition are melted in a non-reactive crucible then cast into an ingot. The ingot is then rolled, extruded, drawn, pressed, heat treated in a suitable atmosphere and chemically treated. The pieces are then machined to achieve the required tolerances. The metallic pieces are then heat treated to produce the desired surface layer by vapor deposition, chemical vapor deposition, physical deposition, electo-plating deposition, or combinations of the above. The pieces may be subsequently heat treated in a controlled atmosphere to produce the desired layer properties through diffusion, recrystalization, dopant activation, or valence changes of metallic ions.

The invention further includes that the layer used in the bonding process could be the following composition of matter. More specifically, a formula for dissipated ceramic comprising alumina (aluminum oxide Al_2O_3) and zirconia (zirconium oxide ZrO_2) and other elements. This mixture is both somewhat electrically conductive and mechanically durable. The tip of a bonding tool will be coated with this material or it could be made completely out of this material. The shape of the tip may be wedge or circular shaped as shown and described in the earlier Figures 1 to 5.

One actual sample was constructed with the following elements:

<u>ELEMENT</u>

Iron
Oxygen
Sodium
Carbon
Zirconium
Silicon
Aluminum
Yttrium

While the range of alumina could extend from 15% to 85% and the range of zirconia from 15% to 85%, another sample included alumina at 40% and zirconia at 60%.

The bonding tip of the present invention could be used for any number of different types of bonding. Two examples are ultrasonic and thermal bonding.

While the invention has been described with reference to specific embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted for elements thereof without departing from the true spirit and scope of the invention. In addition, modifications may be made without departing from the essential teachings of the invention.